INVESTIGATION OF CORRECTOR LENS DEFORMATIONS

12 January 2004

Greg Derylo, derylo@fnal.gov
FNAL / Particle Physics Division / Mechanical Department / SiDet

1.0 INTRODUCTION

As part of efforts for CTIO Blanco 4m telescope camera replacement, NOAO has solicited preliminary corrector design options from two optical engineering resources, Prime Optics and V. Yu Terebizh. Their engineering efforts did not address the mechanical deformations. Due to the large size of many of these elements, the effect of gravitational sag on the elements themselves has been questioned. The purpose of this study is therefore to quantify the magnitude of this affect for the applicable design options. The effect of atmospheric pressure on the dewar window element is also addressed. Corrector element support hardware and thermal deviations are not considered as part of this investigation. Although a similar study could be performed for the filters, their currently unknown size but simple geometry allows simple hand calculation and they will therefore not be addressed here.

Computer models were constructed from the information obtained in each optical report and a finite element analysis was performed. Note that the report documents the optical diameter of each piece and that the actual diameters might have to be slightly larger to allow support along the circumference. This study should therefore be revisited as the project design evolves.

Properties assumed for the fused quartz material are shown below[1]:

Flexural Strength = 50 MPa
$E = 74$ GPa
$\nu = 0.17$
$\rho = 2.21$ g/cc

2.0 ANALYSIS

A test case was first investigated to verify that the FEA results agree with explicit solutions calculated by hand to verify the reasonableness of the results. A simple disk, 100 cm in diameter and 2.5 cm thick, was used for this purpose. For a 0° declination angle (telescope pointing straight up), the deformation, assuming a simply supported edge, can be calculated by hand using Roarkís Formulas for Stress and Strain, 7th ed. Table 11.2 Case 10a.

$$y_c = -q * a^4 * (5 + \nu) / [64 * D * (1 + \nu)]$$

$$\begin{aligned} q &= \rho \text{ A t g / A} \\ &= [(2.21 \text{ g/cc}) * (100*100*2.5 \text{ cm}^3) * (9.81 \text{ m/s}^2) * (.001 \text{ kg/g}) * (\text{N s}^2 / \text{kg m})] / (1 \text{ m}^2) \\ &= 542 \text{ N/m}^2 \end{aligned}$$

$$\begin{aligned} D &= E * t^3 / 12 / (1- \nu^2)] \\ &= (74\text{E}9 \text{ N/m}^2) * (.025\text{m})^3 / 12 / 0.9711 \\ &= 99222 \text{ Nm} \end{aligned}$$

---

[1] Data from Matweb.com for Saint-Gobain Puropsil® B Infrared Grade Low [OH] Optical Fused Quartz.

y_c = -(542 N/m^2) * (0.5 m)^4 * 5.17 / [64 * (99222 Nm) * 1.17] * [1E6 μm / m]
= -23.6 μm

Assuming the sag varies with the cosine of the declination angle, the estimated effect of telescope position is tabulated in the table below. The FEA results found with the IDEAS simulation package are also shown. Excellent agreement (<1%) was found for the 0° case. However, the simple cosine relationship does not match the FEA calcs the further one travels from 0°.

Table 1 ñ Test Case Results

Declination Angle (deg.)	Hand Calc. * COS(Angle) (μm)	FEA Results (μm)	Hand / FEA - 1 (%)
0	-23.6	-23.7	-0.4
15	-22.8	-22.5	+1.3
30	-20.4	-19.8	+3.0
45	-16.7	-15.8	+5.7
60	-11.8	-10.7	+10.3
75	-6.1	-4.6	+32.6

2.1 Prime Optics 2.1° Design

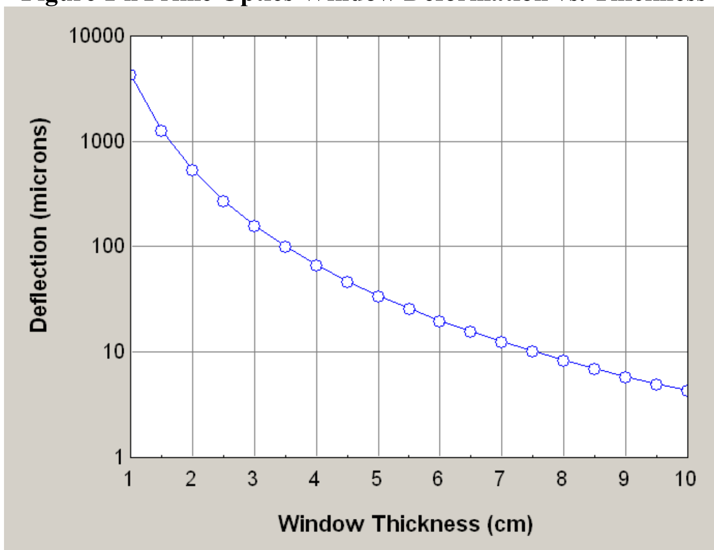
Analyses were then performed for elements in the Prime Optics design, as shown in Table 2. Due to thicker geometries, much smaller deflections were found at 0° even for the largest elements. Due to the scale of these deflections, cases at different declination angles were not run. Additional studies can be performed at a later date if necessary.

Table 2 ñ Prime Optics 2.1° Design Results at 0° Declination

Element	Deflection (μm)
C1	2.6
C2	0.6
C3	0.2
C4	0.3
Window, with atmospheric pressure applied (D=0.5m assumed)	1263 (σ = 33.5 MPa)

Note that the window, with F = A*P = [π * (9.843 in)^2] * [14.7 psi] = 2.2 tons, has a very large deformation and a high stress (33.5 / 50 = 67% of advertised strength). The effect of deformation on the optics should be understood before a new thickness can be suggested. As a guide, however, the following plot, which was generated using the hand-calc technique above, shows deflection vs. thickness for a 0.5m diameter flat window.

Figure 1 ñ Prime Optics Window Deformation vs. Thickness



2.2 Terebizh 2.4° Design

Due to the small deflections found for the first four elements of the Prime Optics design, only the largest element and the window were studied here. The results are shown in the following table. Further study of this design can be performed if necessary.

Table 3 ñ Terebizh 2.4° Design Results at 0° Declination

Element	Deflection (μm)
1	1.0
2	(not analyzed)
3	(not analyzed)
4	(not analyzed)
5	(not analyzed)
Window, with atmospheric pressure applied	211 (σ = 17.7 MPa)